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Resistance of concrete based on treated mud to sea water attack

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ABSTRACT

All the dams in the world are exposed to the phenomenon of sedimentation, but with velocities that differ from one region to another. This phenomenon has been widely reported in Algeria. Dredging is a vital activity in the operation of dams, but the amount of sediment discharged by dredging operations downstream of the structure can lead to long-term pollution of the rural environment. This study focuses on the valorization of the vases resulting from these dredging operations at the dams as the case of Chorfa dam (western Algerian). The objective is to propose economically competitive formulations that are easy to implement and which allow these materials to be used in the manufacture of ordinary concretes by partial substitution of cement (10, 20 and 30%). The sludge is treated by calcination at 750°C to make it active. Seawater attack tests were conducted on the concretes to determine their durability. The results obtained confirmed the possibility of developing concretes incorporating the calcinated sludge at dosages of up to 30% without compromising the quality of these concretes in terms of behavior against seawater aggressions meeting the economic, ecological and technological objectives.

1 Introduction

For the management of sediments resulting from dredging dams, the solution is mainly limited to disposal on land. This solution is considered too expensive but also dangerous for the environment [1]. In a context of sustainable development, the recovery of sediments in civil engineering makes it possible to cope with the lack of deposits and the depletion of aggregates.

The construction industry consumes large quantities of aggregates, most of which comes from natural quarries. In addition, the annual volume of dredged sediment is several million cubic meters, a large volume that can be a source of aggregate supply for the construction sector.

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Sediments have a very variable recovery potential in civil engineering: either in road construction, or as aggregate in concrete, or as raw material in the manufacture of cement or bricks [1].

In the cement industry, the search for a less expensive binder using sediments dredged from dams, in particular the Chorfa dam (western Algeria), has become a major concern to improve the deficit in Portland cement manufacturing [2].

The partial substitution of a certain quantity of Portland cement by these sediments, which must undergo a thermal treatment by calcination to make them active and obtain a calcined silt, can be advantageous not only economically, ecologically, rheologically but also from the point of view of resistance [3, 4].

The valorisation of calcined mud as a partial substitute for cement in concrete has been widely studied in recent years [5, 6].

The literature clearly shows that it is an active pozzolan and helps improve the early and long-term mechanical properties of concrete [7, 8].

This study is part of a long research on the durability of concretes based on 10, 20 and 30% calcined mud. It aims to measure the resistance of these concretes to the attack of seawater and their variation in mass.

2 Experimental program

All tests were carried out under hygrothermic conditions, at a temperature of 20 °C±1°C and 50% ± 2% relative humidity

2.1 Materials

2.1.1 Cement

Portland CEMI 42.5 R cement, from Zahana cement plant in western Algeria, was used in this study. Its Blaine specific surface area is equal to 3180 cm^2/g according to the Algerian norms NA442 [9] and its chemical and mineralogical compositions are reported in Tables 1 and 2.

Table 1- Basic chemical composition of cement CPA-CEM I 42, 5

Components	**SiO2**	**Al2O3**	**Fe2O3**	**CaO**	**MgO**	**SO3**	**K2O**	**Na2O**	**PF**	**RI**
Content (%)	22.30	5.10	3.99	63.60	1.43	1.24	0.70	0.34	1.18	0.36

Table 2- Mineralogical composition of clinker

Components	**C_3S**	**C_2S**	**C_3A**	**C_4AF**	**CaO Free**
Content (%)	53.13	23.55	6.76	12.13	< 01

2.1.2 Sludge

The whole quantity of the sludge used is taken from the discharge zone downstream of Chorfa dam, with specific Blaine surfaces equal to 7830 cm^2 / g. We treated the mud according to the following steps [10]: After drying in an oven at 105° C., the vases were crushed and sieved by dry methods. The sieves which pass through 80µm and which represent more than 95% of the sample are recovered for cooking.

Calcinating operations required some precautions: to avoid thermal shocks the cooking speed was set at 5° per minute, the calcination temperature 750° C was kept constant for 5 hours [11]. The product thus obtained (calcinated vase) was kept away from air and moisture.

The process of preparing and transforming the mud sample by heat treatment is described in the following steps (Figure. 1).

Fig. 1– Steps for mud preparation

The chemical characteristics of the mud are summarized in Table 3 [12, 13].

Table 3- Chemical characteristics of Chorfa mud

Components	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**	**PF**
Content (%)	47,36	15,75	7,43	23,08	2,67	0,17	2,97	0,37	1,76

The impact of the Al_2O_3 content is not very significant because the percentage of substitution does not exceed 30%, nevertheless, it can be estimated that this contribution of Al_2O_3 reduces the SO_3 / Al_2O_3 ratio in the concrete, and therefore reduces the risk of secondary etringitis formation.

The Figure. 2a and Figure. 2b shows the EDS analysis carried out on samples of calcinated vase [14, 15].

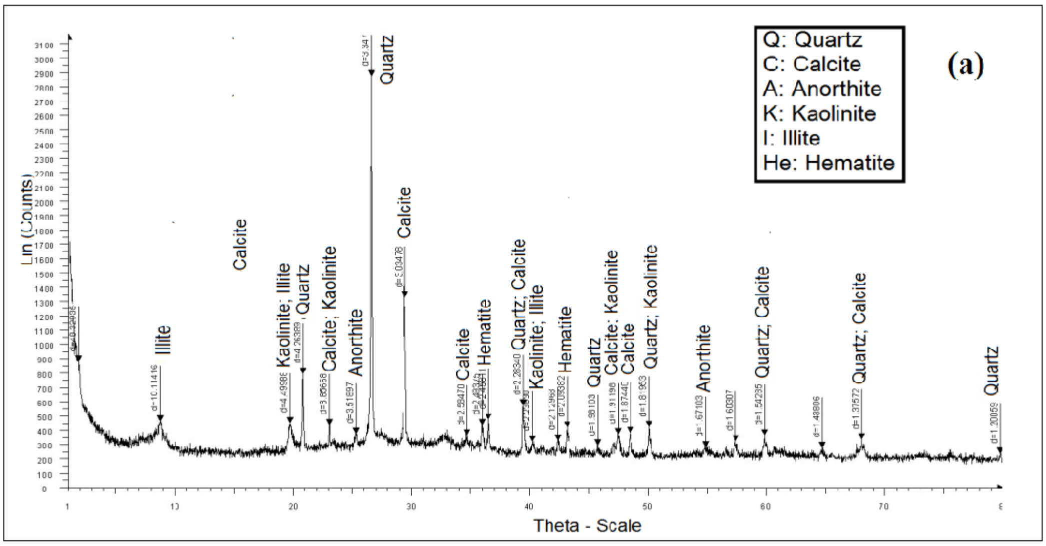

Fig. 2a– XRD analysis of calcinated mud

The chemical and mineralogical analysis of the mud under study Figure. 2a reveals the presence of the essential minerals, such as silica and alumina that make up the most common hydraulic binders [16, 17].

Figure. 2b shows the rough and porous appearance of calcinated mud grains. It would be sufficient to therrmically activate the clay minerals so that they can react with water if the limestone content is adequate to form compounds which set and harden at ambient temperature [18, 19].

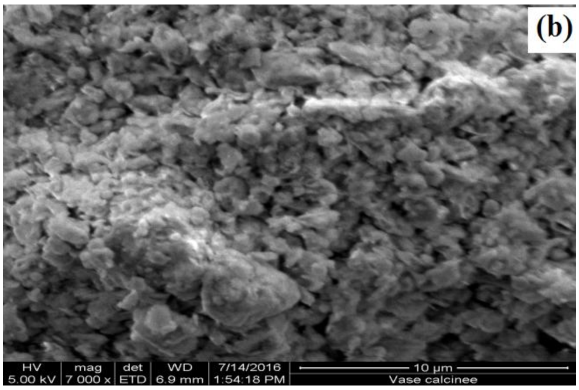

Fig. 2b– EDS analysis of calcinated mud

2.1.3 Aggregates

The aggregates used in the manufacture of concretes are of limestone nature and come from the quarry of Hassnaoui in Sidi-Belabbes located in western Algeria.

2.1.3.1 Sand

The main physical characteristics of this sand 0/3 are shown in Table 4.

Table 4- Physical characteristics of quarry sand

Absolute density (g/cm^3)		2,68
Sand equivalent (%)	**Visual**	77.45
	Piston	74.00
Fineness modulus		2,63

2.1.3.2 The gravel

Two granular classes are retained: 3/8 and 8/15. They have an absolute density of 2.65 g/cm^3. The granulometric curves of the aggregates are given by Figure. 3.

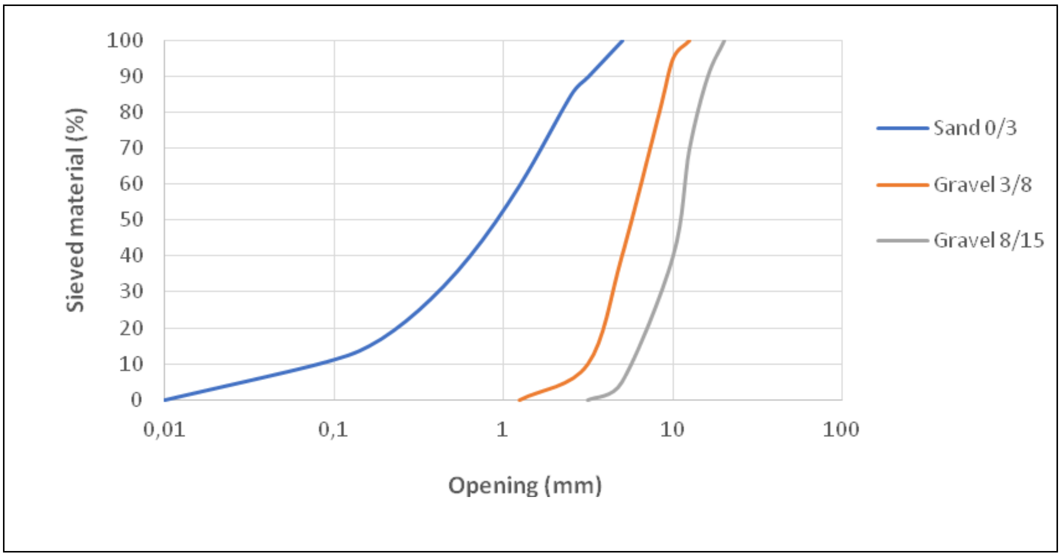

Fig. 3– Grain size distribution curves of aggregates

2.1.4 The additive

A water-reducing plasticizer, namely Sika Plastiment BV 40, was used for additive-based formulations in order to have concretes of the same consistency (plastic) while keeping the same W/B (water/binder) ratio.

2.1.5 Sea water

The sea water used in our sustainability study comes from the Salamandre beach in the Mostaganem region. The chemical analysis of the sea water is given in Table 5.

Table 5- Summary table of the chemical characteristics of the sea water used (National Laboratory for Habitat and Construction - Chlef Unit)

Chemical Constituents	Water Foundation (mg/l)
Calcium (Ca^{++})	376.75
Magnesium (Mg^{++})	972
Sodium (Na^{+})	ND
Chlorides (Cl^{-})	14200
Sulfates (SO_4--)	3000.6
Carbonates (CO_3--)	600
Bicarbonates (HCO_3--)	915
pH	4.5
Dry residue	1100
Suspended matter	Limpid
Odour	Without
Color	Transparent

2.2 Studied formulations

(Mud-ordinary Portland cement concrete, MOPCC)

Four concrete formulations were developed. Three of them involved various proportions of mud (MOPCC 10%, MOPCC 20% and MOPCC 30%), and the fourth one is control concrete (CC 00%) for the need of comparison. Table 6 gives the compositions of the different concretes under study.

Table 6- Formulation of concretes

Designation	Cement kg/m^3	P/B (Plasticizer/ Binder) (%)	Addition kg/m^3	Gravel kg/m^3		Sand kg/m^3	Water kg/m^3	W/B (Water/ Binder)	P kg/m^3
				3/8	8/15				
CC 00%	402	00	00	179	912	663	201	0.5	00
MOPCC 10%	363.6	0.3	35.33	179	912	663	199.4	0.5	1.19
MOPCC 20%	324.8	0.4	71.02	179	912	663	197.9	0.5	1.58
MOPCC 30%	286.3	0.65	107.31	179	912	663	196.8	0.5	2.56

In fact the plasticizer dosage increases as the substitution dosage increases because of the great fineness of the sediments namely 7830 cm^2 / g, so to keep the Water to Binder ratio constant it is advisable to compensate by a dosage higher in plasticizer in order to keep more or less the same workability of concrete.

The sagging of concretes is found to be in accordance with standard NF P 18-451 and also with the slump required for the formulation of our concretes (8 ± 1 cm).

2.3 Test Methods

2.3.1 Compression testing

The durability of concrete in various more or less aggressive environments (sea water) can be quantified by the evolution of their mechanical strengths and the variation in mass. Solutions are renewed every month.

To evaluate the durability of the concretes with the addition used and to be able to evaluate the effect of this addition on the resistivity to the attacks of the sea water, mechanical, physical and chemical tests were carried out on immersed concrete test pieces for 720 days in seawater solutions. The procedure was as follows:

- Monitoring of mass variation;
- Monitoring of the evolution of the resistance to compression;
- Visual analysis of the condition of the test pieces;

3 Results and analyses

3.1 Variation of mass in the solution of sea water

The change in the mass of the samples immersed in the sea water is represented as a function of the immersion time in Figure. 4. The reference is the last measurement before immersion.

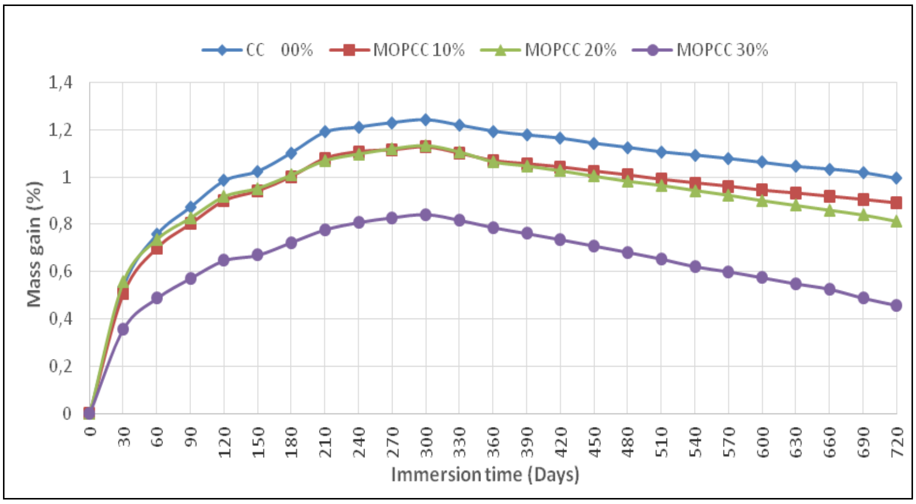

Fig. 4– Variation of the mass of the samples immersed in the solution of the sea water

The specimens immersed in the solution of the sea water, are distinguished by an increase of the mass from the first days of the immersion and there is a continuity of increase up to 320 days.

The MOPCC 30% has a lower weight gain than the CC 00%, MOPCC 10% and MOPCC 20%. The weight gain of the MOPCC 10% is almost similar to that of the MOPCC 20% if the dispersion of the measurements is taken into account. The CC 00% is more susceptible to degradation by attacking seawater in the long term [20, 21].

The various chlorides dissolved in seawater, in particular magnesium chlorides ($MgCl_2$) and calcium chlorides ($CaCl_2$), generate aggressive chemical reactions for the concretes which result in dissolving the lime and precipitating ettringite (crystallization of expansive salts, decalcification, precipitation of insoluble compounds, ionic attacks, dissolution of portlandite, etc.).

Magnesium sulphat solutions are more aggressive to concrete than sodium sulphat solutions. The portlandite present in the hydrates is attacked by magnesium sulphat to form secondary gypsum $CaSO_4$, $2H_2O$ and brucite $Mg(OH)_2$ in the concrete. This secondary gypsum dissolves in part by increasing the porosity of the concrete. Mg^{2+} ions also react with CSH.

The reaction with the calcium aluminate hydrate from C_3A forms ettringite C_3A, 3Ca SO_4, $32H_2O$. This ettringite crystallizes with a large increase in volume, hence the appearance of cracks that accelerate the mechanism of destruction [22, 23]. Magnesium chloride $MgCl_2$ is the most aggressive chloride. It reacts with portlandite to give partly soluble calcium chloride CaCl2, which increases the porosity of the concrete. The other part reacts with the hydrated lime aluminate to form chloroaluminates 3CaO, Al_2O_3, $CaCl_2$, $10H_2O$ (Friedel salt) [24, 25]. This salt, also expansive, causes the cracking of the concrete. CO_2 ions in the presence of active silica transform ettringite into thaumasite $CaCO_3$, Ca SO_4, Ca SiO_4, $15H_2O$, leading to risks of expansion and cracking. In some special cases, the CO_2 content can be high and the sea water becomes very aggressive [26, 27]. This occurs in estuarine waters or closed bays where accumulation of organic matter results in a higher concentration of CO_2

3.2 Monitoring of compressive strength

The compressive strengths were monitored on 10x10x10 cm^3 test pieces immersed in the sea water solution. Figure. 5 and Figure. 6 show the effect of the partial substitution of the CEMI cement by calcinated sludge on the evolution of the compressive strength of the concretes immersed in a solution of the seawater.

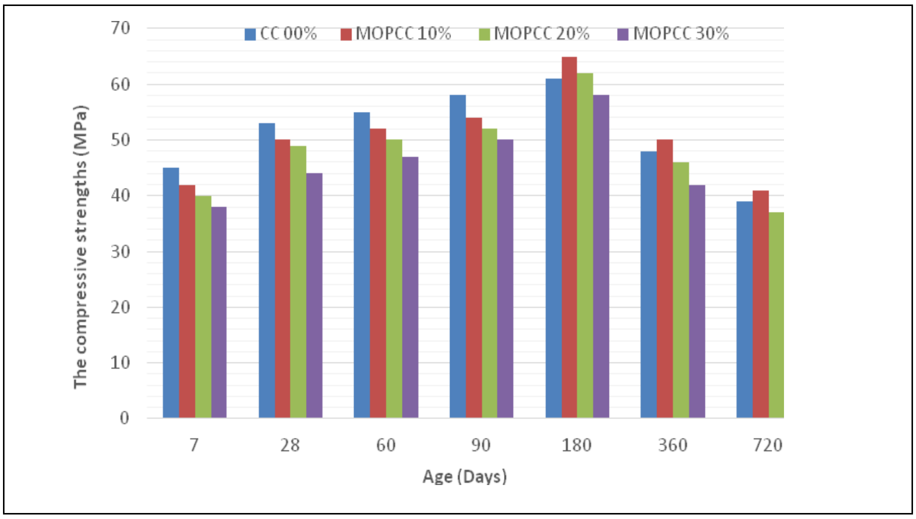

Fig. 5– Evolution of the compressive strength of submerged concretes in the sea water solution

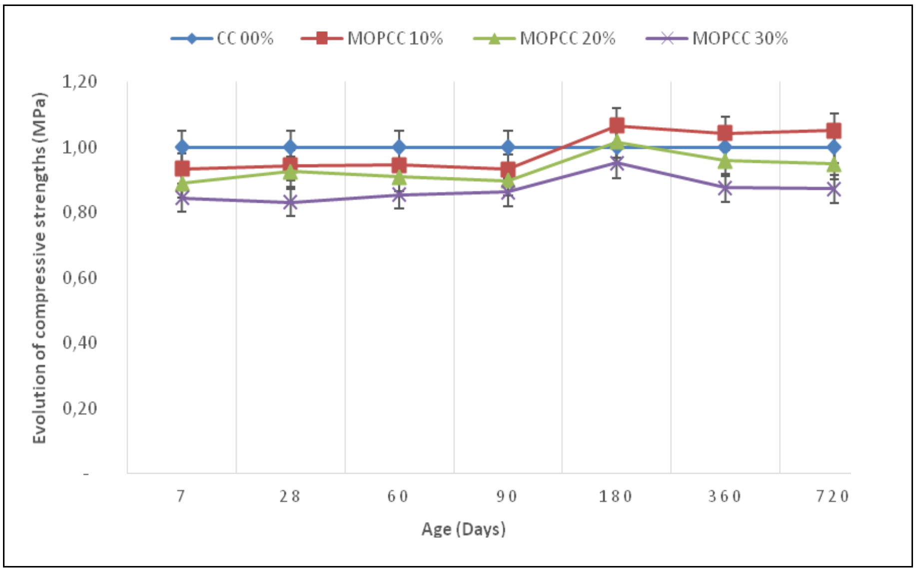

Fig. 6– Evolution of the compressive strength of submerged concretes in the seawater solution compared to those of the control concrete

Like the results of immersion in the solution of the sea water, it can be seen that the compressive strength of the CC 00% dropped as early as the 180th day of storage in solution [28, 29]. The decrease of the resistance is of the order of 13 MPa. [30]. On the other hand, the other concretes are also affected from the 180th day of immersion [31, 32].

MOPCC 10%, MOPCC 20% and MOPCC 30% respectively have a maximum resistance to 180 days of immersion age (65, 62 and 58 MPa) to decrease considerably to 720 days (41, 37 and 34 MPa) but taking into account the dispersion of the measurements, we can say that the resistance is less stable for these types of concrete [33, 34].

Several studies show that the increase in compressive strength before falling to a certain age is due to the formation of ettringite and gypsum which fill the micropores leading to a dense structure beyond a certain age [35, 36].

Formation of these expansive products causes the destruction of the hardened cement paste and its cracking, which negatively affects the mechanical properties of the concretes [37, 38].

It can also be noted that the MOPCC 10% and MOPCC 20% concretes exhibit better strengths than other concretes at 720 days of immersion in the seawater solution [39, 40].

3.3 Visual inspection

Photos were taken to evaluate signs of external deterioration of the concrete test specimens after 720 days of immersion in seawater Figure. 7.

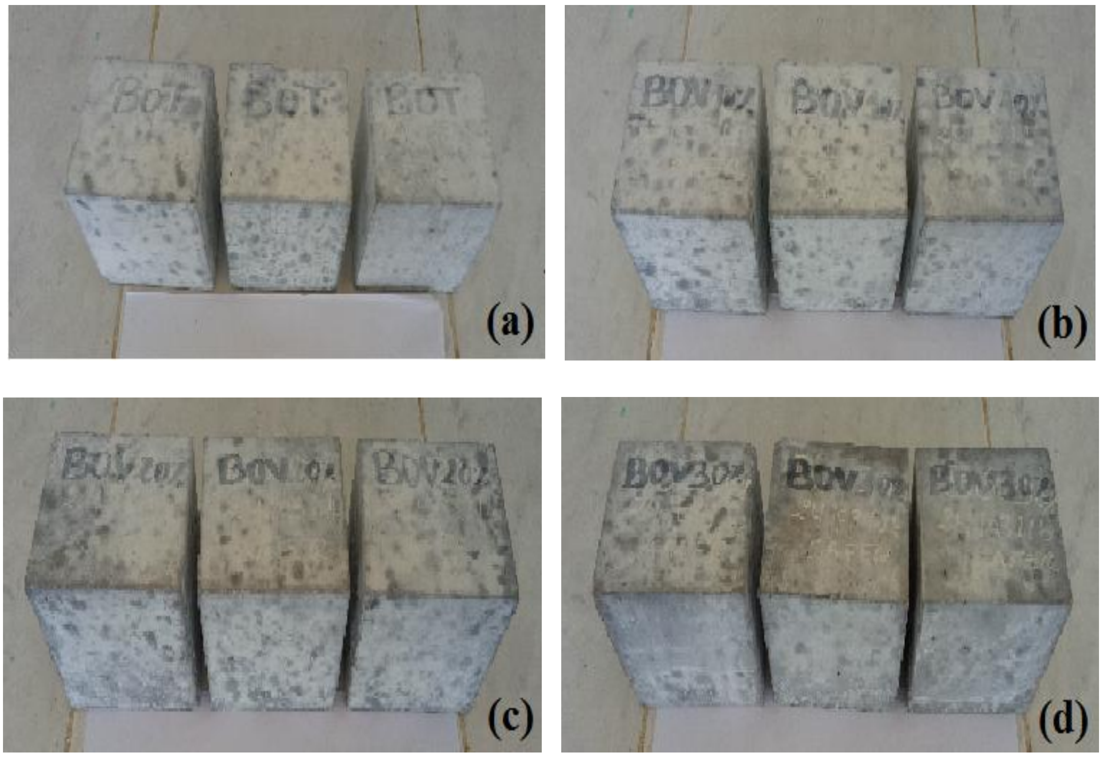

Fig. 7– Samples of different concretes, after 720 days of immersion in the seawater solution a) CC 00% b) MOPCC 10% c) MOPCC 20% d) MOPCC 30%

Figure. 7 shows no significant evidence of degradation of the various samples. In addition, visual examination of the concrete after 3 years of immersion (Figure. 8) shows a slight crack around the corners and edges of the test pieces and the formation of a whitish layer on the outer surface of the samples and which characterizes the triggering of the formation of the gypsum. This explains the reduction of the mass of this concrete between 180, 720 and 3 years of immersion in the solution of the sea water.

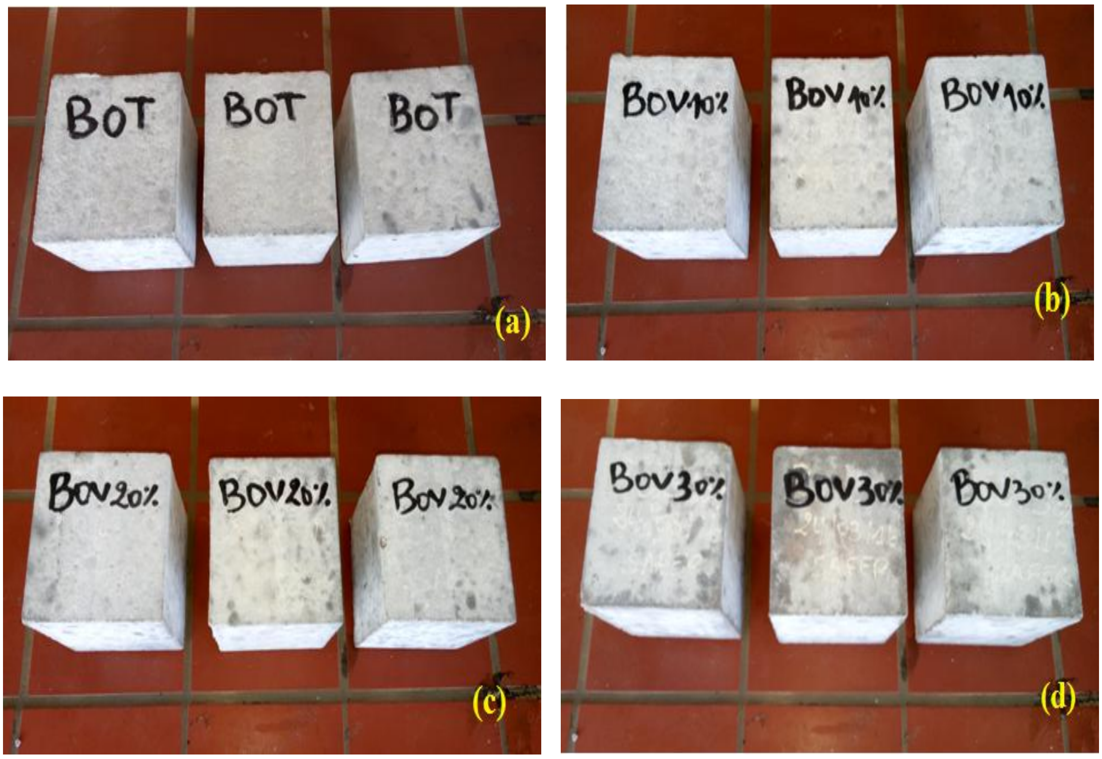

Fig. 8– Samples of different concretes, after 3 years of immersion in the seawater solution
a) CC 00% b) MOPCC 10% c) MOPCC 20% d) MOPCC 30%

4 Conclusions

This study allows confirming the possibility of valorizing the mud from Chorfa dam as partial cement replacement material in concrete. This could solve the problem of its storage, thus making our country more environmentally-friendly, and at the same time may contribute to the national economic development. The possibility of valorizing mud, resulting from the dredging operations of dams, leads us to no longer consider this material as waste, but as a material meeting the principles of sustainable development.

The main conclusions reached are:

- Increasing the Blaine specific surface area of the cement and mud mixture slightly accelerates the setting.
- The immersion of the samples of MOPCC10, 20, 30% calcinated sludge and CC 00% control concrete in the sea water solution enabled us to show that, in fact, concrete with calcinated sludge is more resistant to these types of attacks.
- The possibility of upgrading the sludge (thermally activated in order to transform the mineral structures which are in a stable natural state into amorphous structures) with the aim of making a substitute for the hydraulic binders of current use seems feasible. Given the results of this study, new parameters can follow this work by considering to have one part of cement replaced by the calcined sludge and to study the optimum and / or maximum percentage of substitution as well as their influence on physico parameters mechanical properties such as modulus of static and dynamic elasticity and durability of concrete by gas permeability and mercury porosity tests.

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